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Title:	We are made of star stuff: How stars (and planets) are created
Author(s):	Smullen, Rachel Ann
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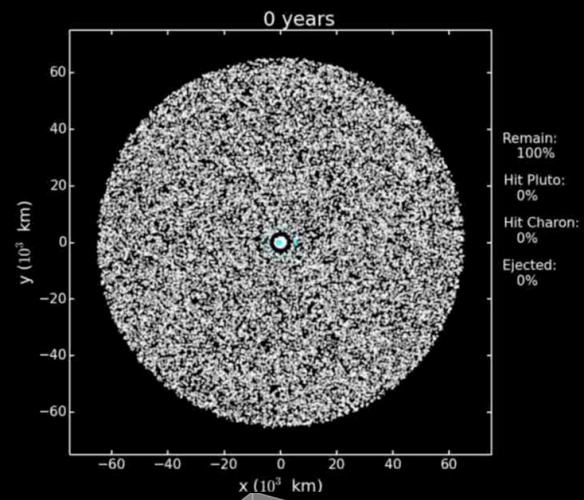
WE ARE MADE OF STAR STUFF

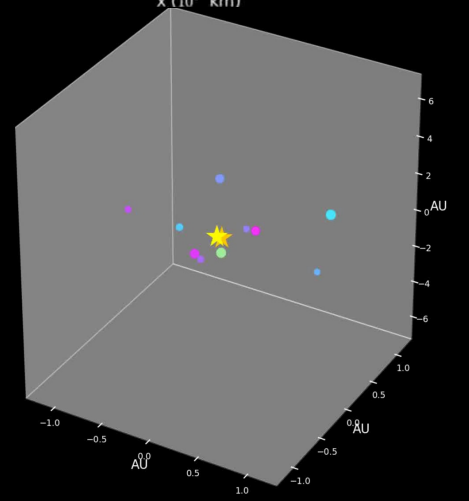
How stars (and planets) are created

Rachel Smullen
LAHS Astronomy Club

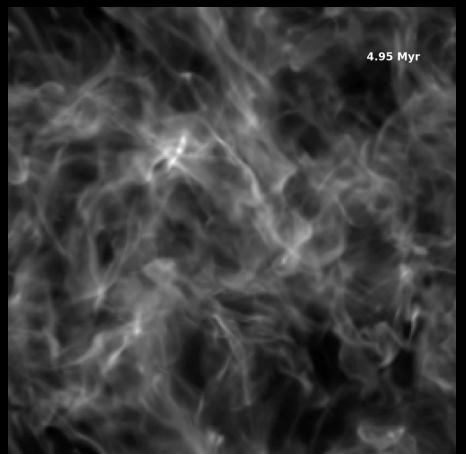
About Me

- Computational (astro)physicist @ LANL
  - I use simulations to study things like
    - Pluto-Charon and the Kuiper Belt
    - Exoplanets
    - Star formation



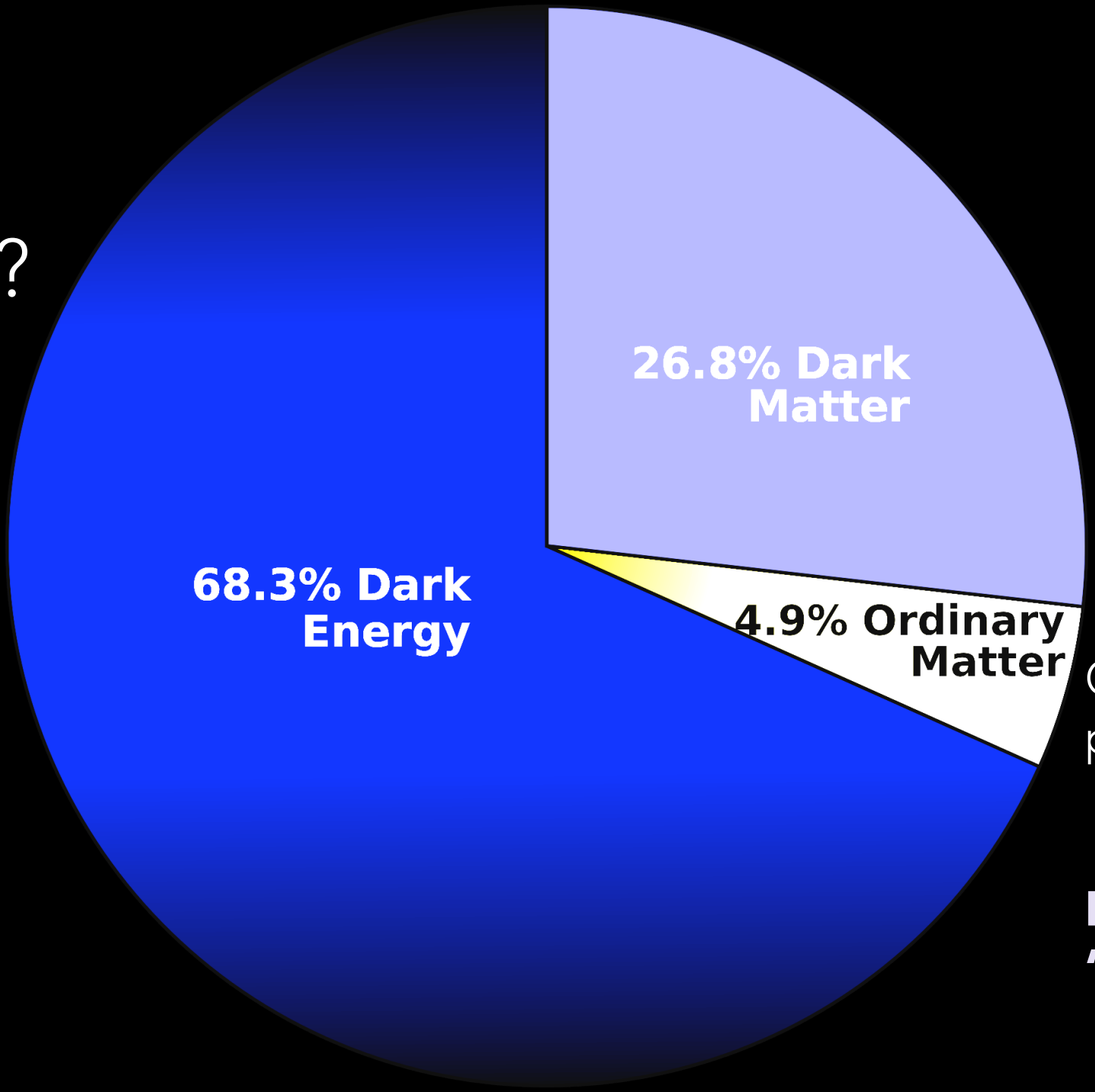


- PhD from University of Arizona (Tucson)
- BS from University of Wyoming (Laramie)
- Hobbies: Books, movies, hiking, travel, cooking, eating…



Stars make up most of what we *see* in the universe.

What's in the Universe?



Galaxies, stars, planets, people

But what is "ordinary matter"?

Image credit: DES

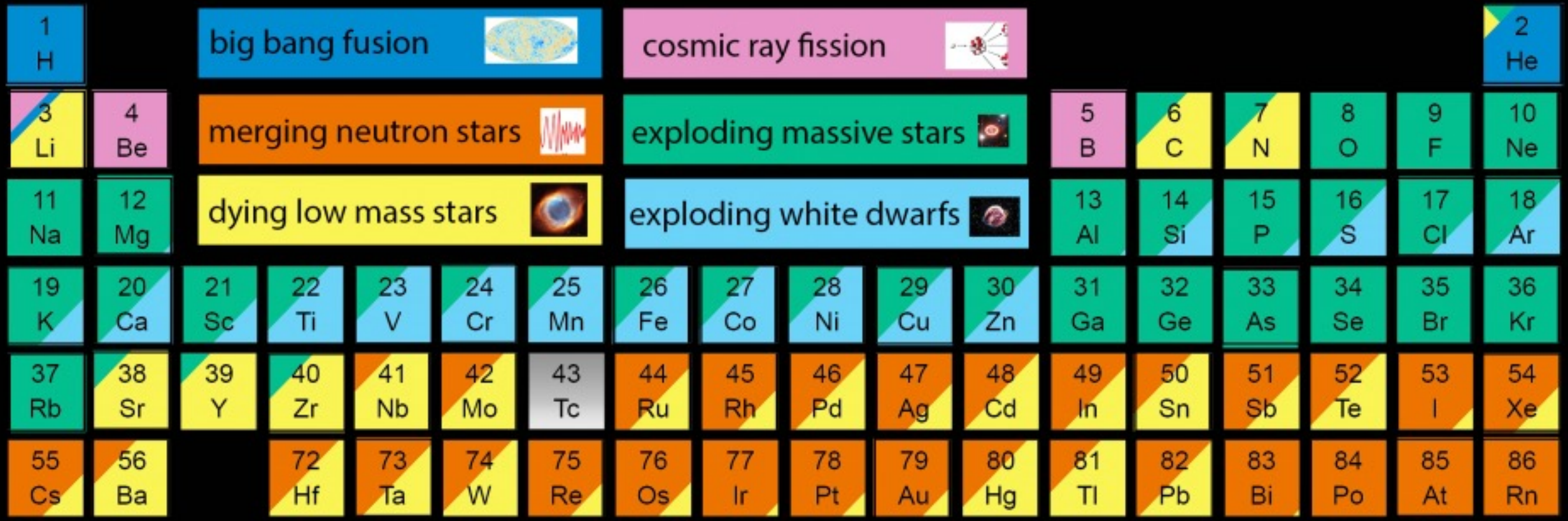


Image credit: Jennifer Johnson

Stars are born from giant, collapsing clouds of gas (and dust)

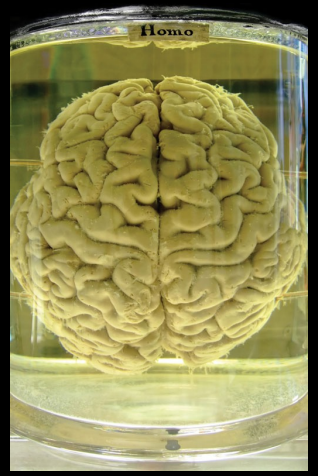
The end.

But really, it's just the beginning…

Molecular clouds are collections of mostly hydrogen (plus other stuff) that are floating around in space

Image credit: ESO

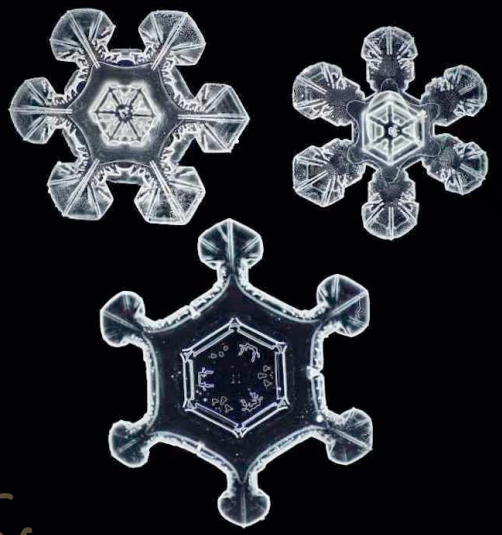
But molecular clouds contain a lot of "other stuff" that is important to humans!



We see atoms, molecules, and solid stuff.
Each plays a role in how stars and planets form.

We see things like

- Ammonia
- Formaldehyde
- Water
- Raspberry flavor (ethyl formate)
- Dust
- Ice
- & lots more!

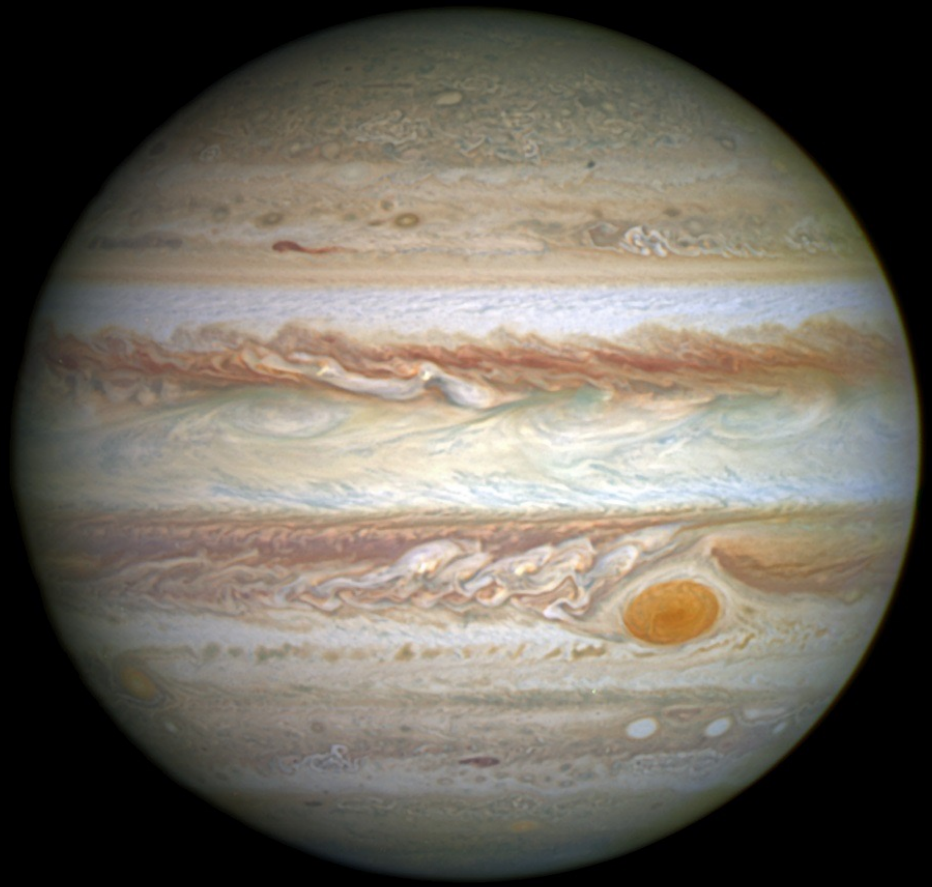


Star formation requires lots of physics working together over millions of years

Molecular clouds are where many different physical processes come together. Let's explore!

Image credit: M. Petrasko

Gravity: mass pulls stuff towards itself



$$F \propto \frac{M\ m}{r^2}$$

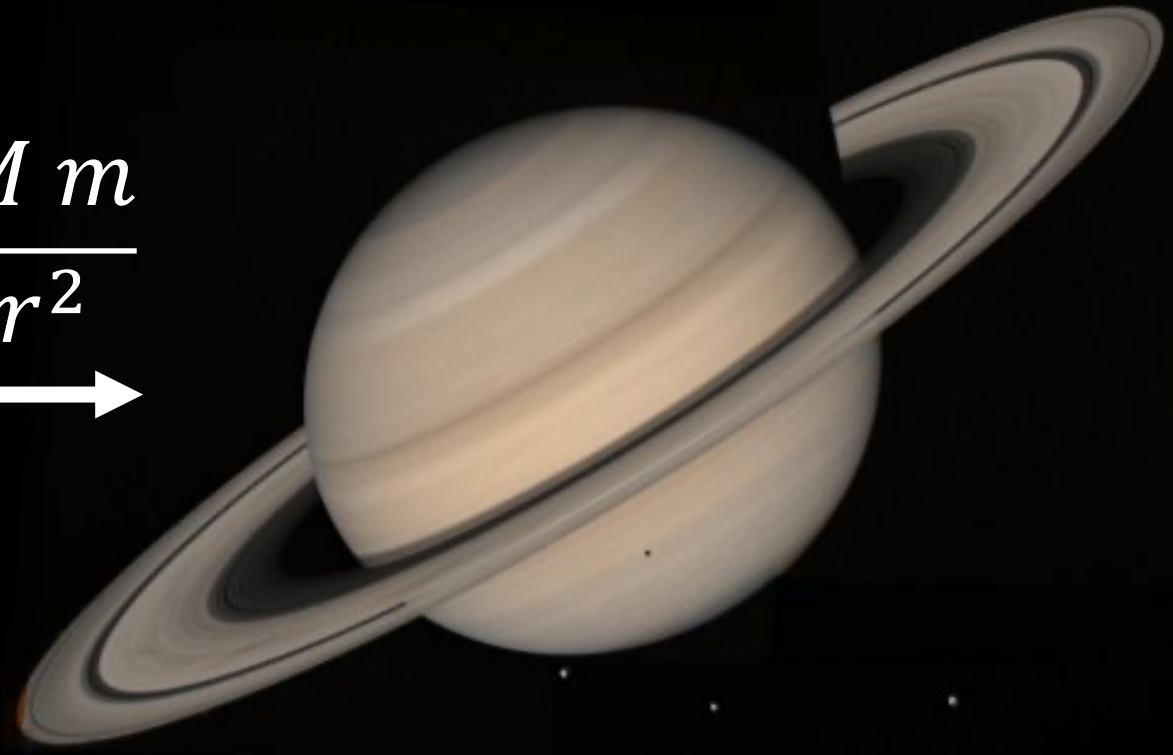


Image credit: NASA

Hydrodynamics: the motion of fluids

Image credit: M Oblinksi

Turbulence: the chaotic motion of fluids

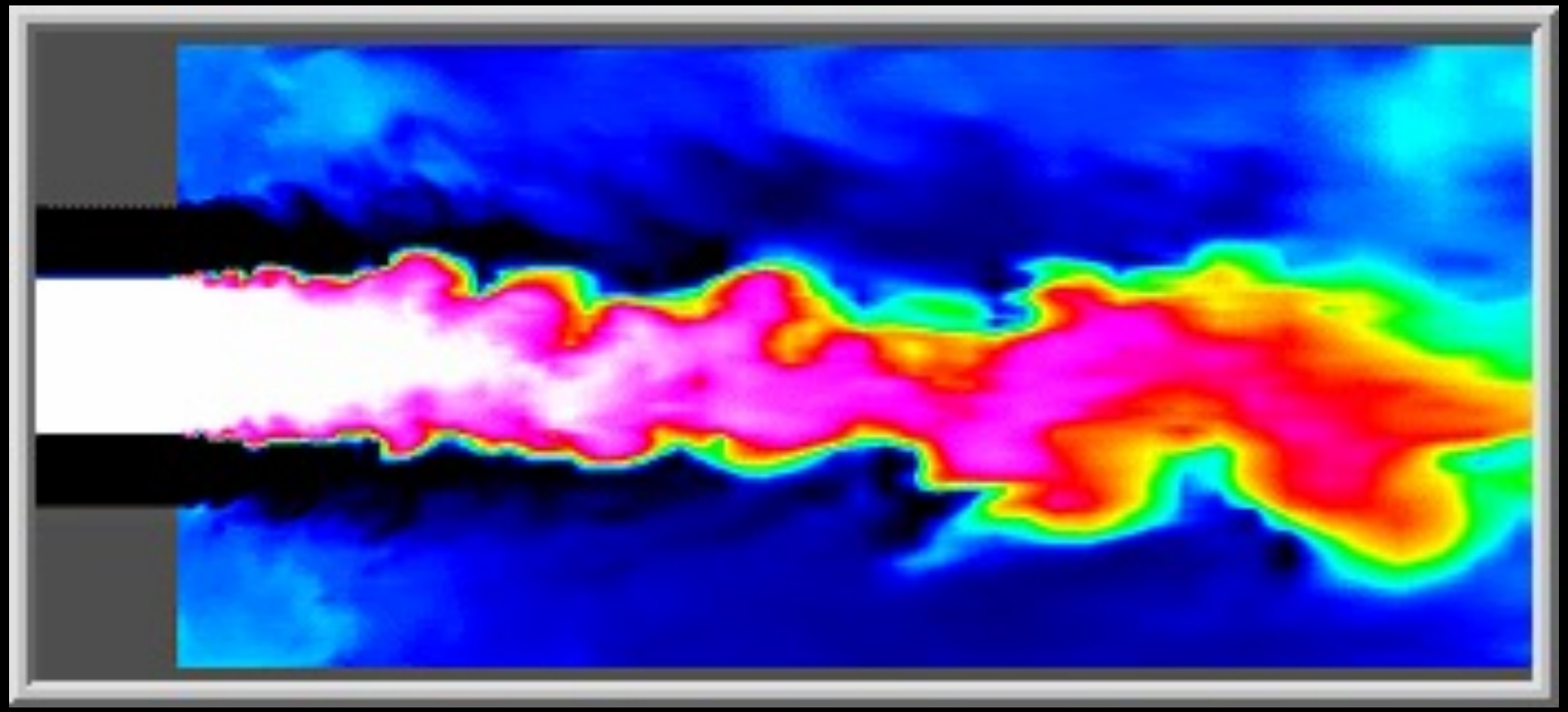


Image credit: James Schombert

Magnetic fields:
promote or hinder motion in a direction

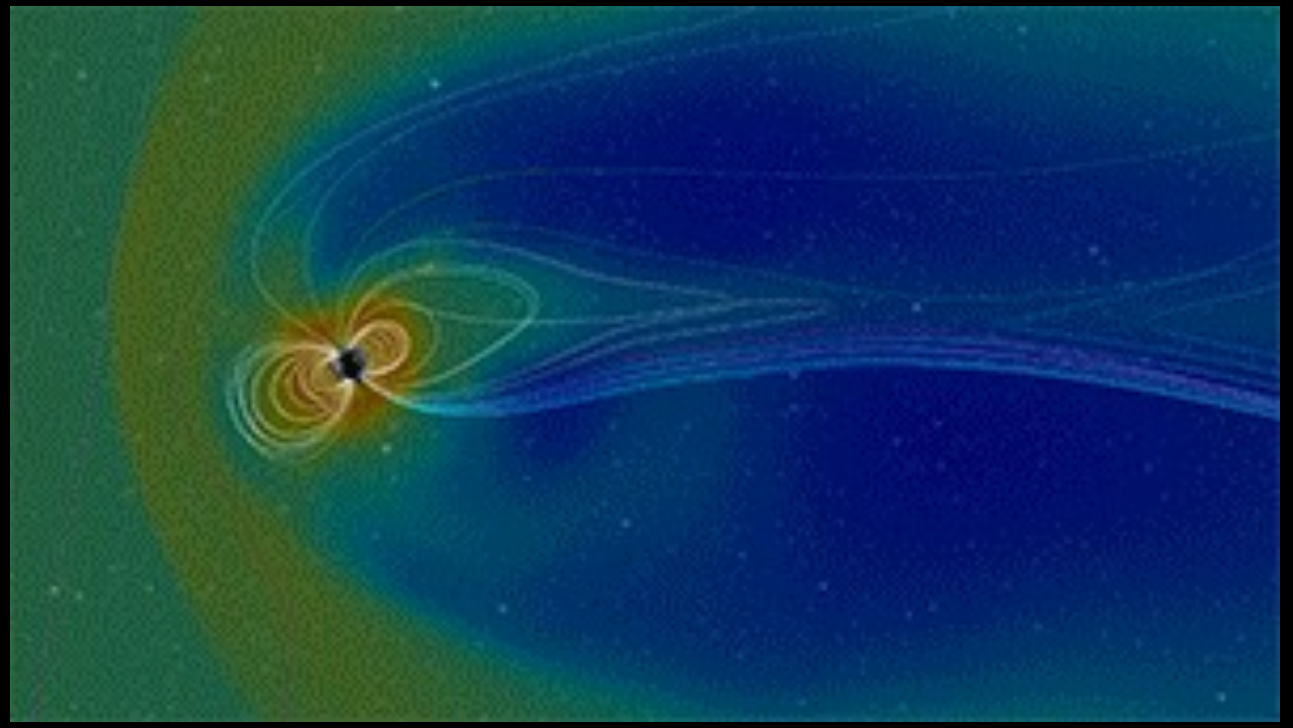
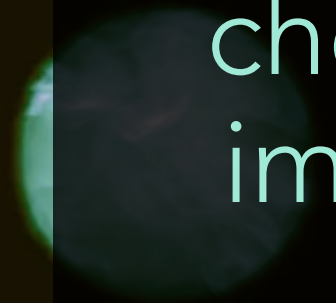


Image credit: NASA

Radiation: heat gas and make a ‘wind’

There’s also some other processes like chemistry, shocks, etc. that become important later, but we won’t cover those today



0 kyr

Image credit: Evan Schneider

Putting it all together…

Let’s look at the steps in a little more detail

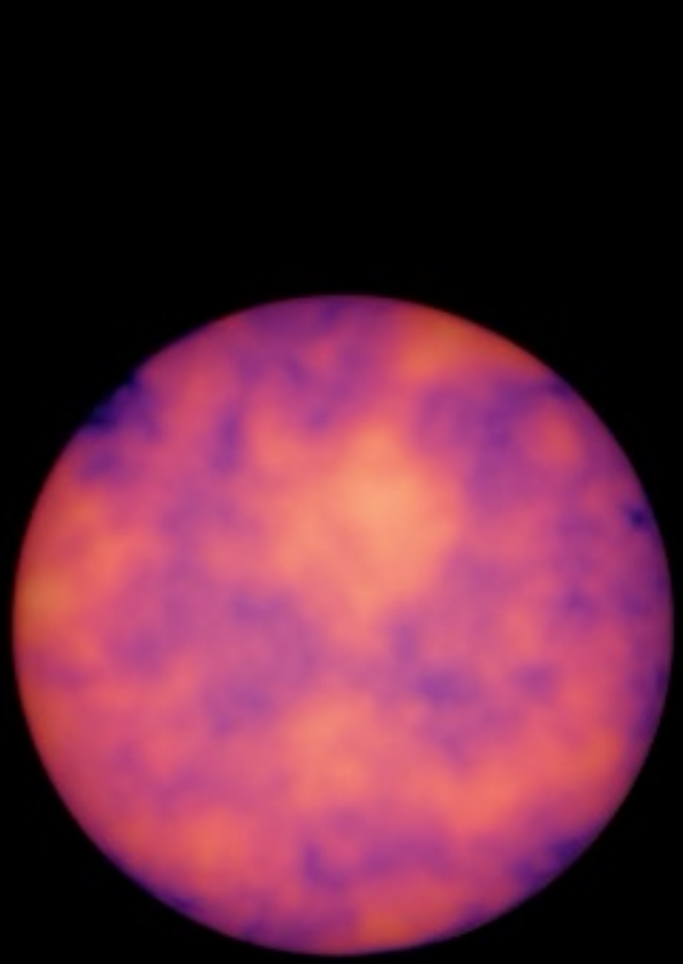


Image credit: Mike Grudić/STARFORGE

The molecular cloud is minding its own business until something happens nearby, disturbs it, and it begins to collapse.

Our cloud will go on to form ***hundreds to thousands of stars***

Image credit: NASA

The cloud collapses into ***filaments*** which then fragment into ***cores***.

These cores contain the material from which individual stars form.

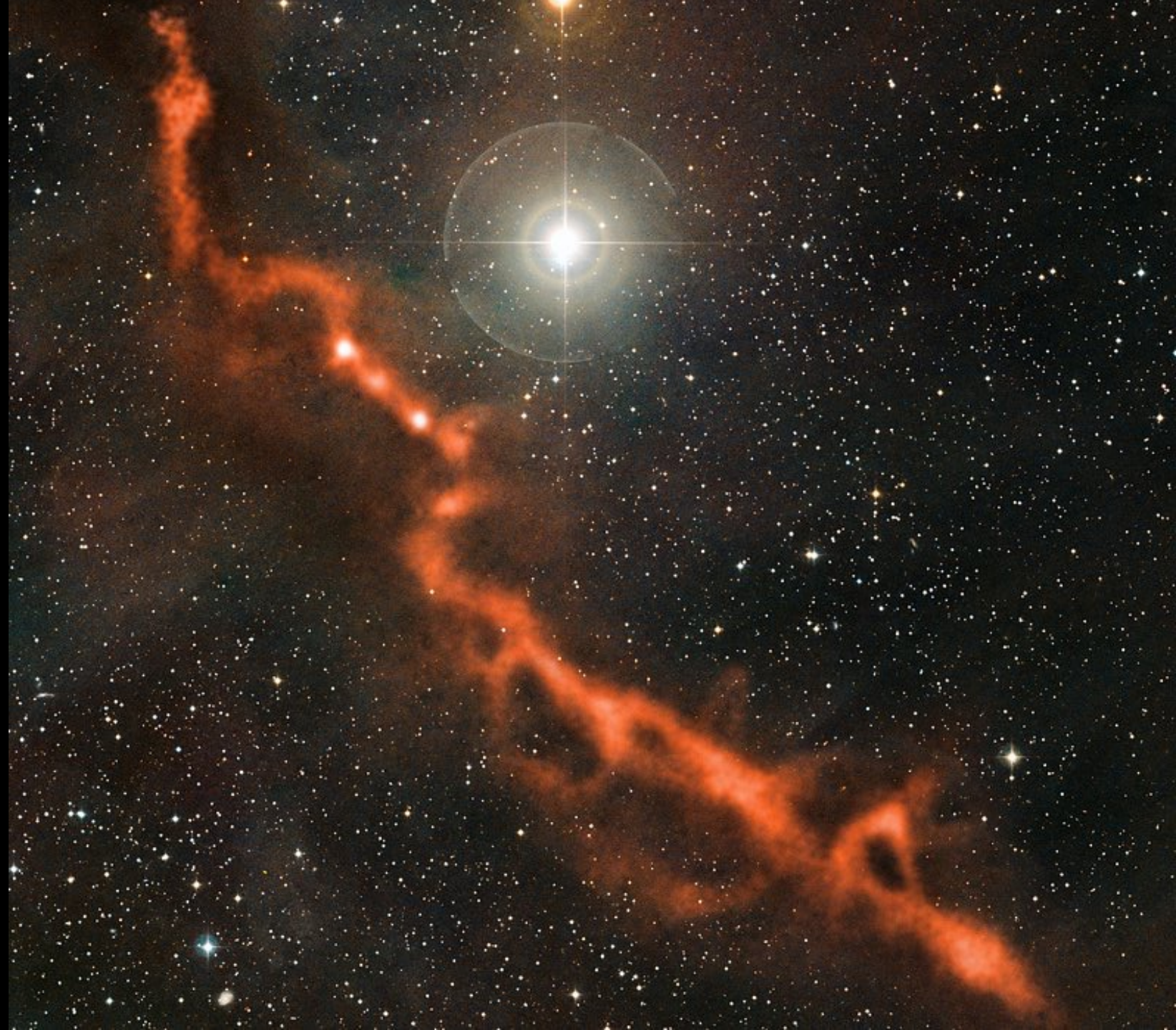
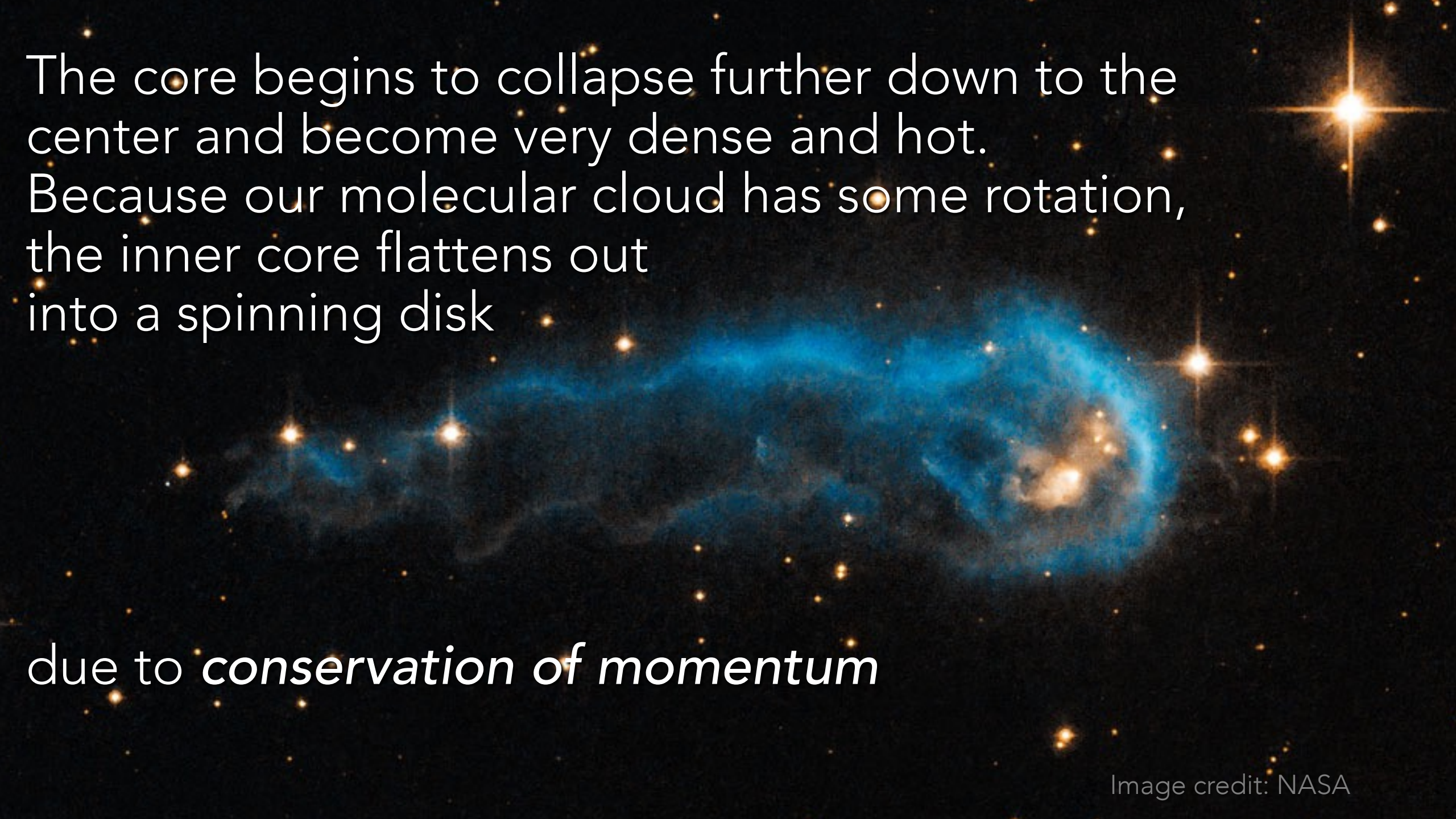


Image credit: ESO



The core begins to collapse further down to the center and become very dense and hot.
Because our molecular cloud has some rotation, the inner core flattens out
into a spinning disk

due to *conservation of momentum*

Image credit: NASA


Material at the disk center collects to form a *protostar*:
a baby star not yet powered by nuclear fusion
Image credit: NASA

Material ***accretes*** onto the growing protostar.

But not all of the gas can make it into the star.

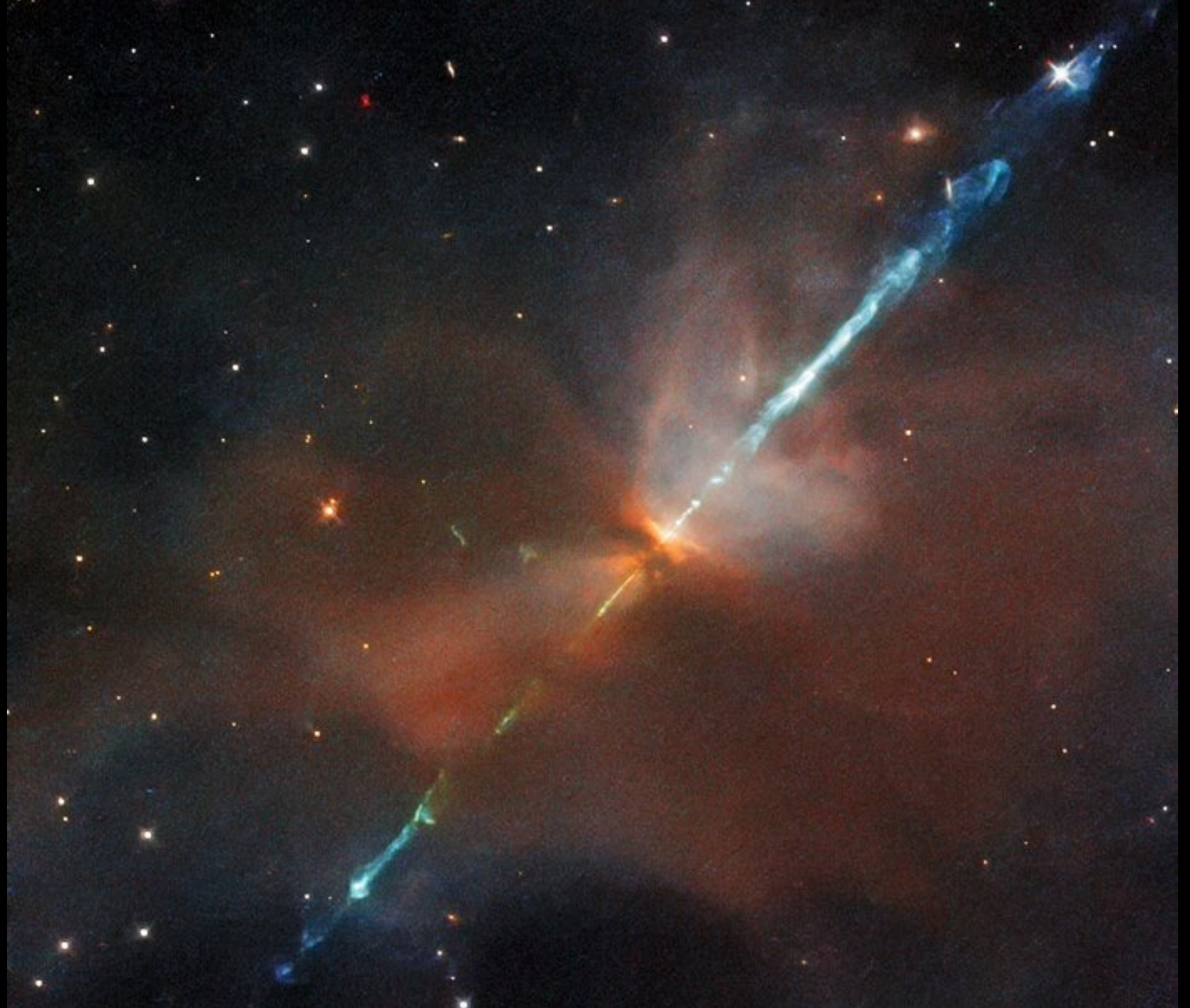
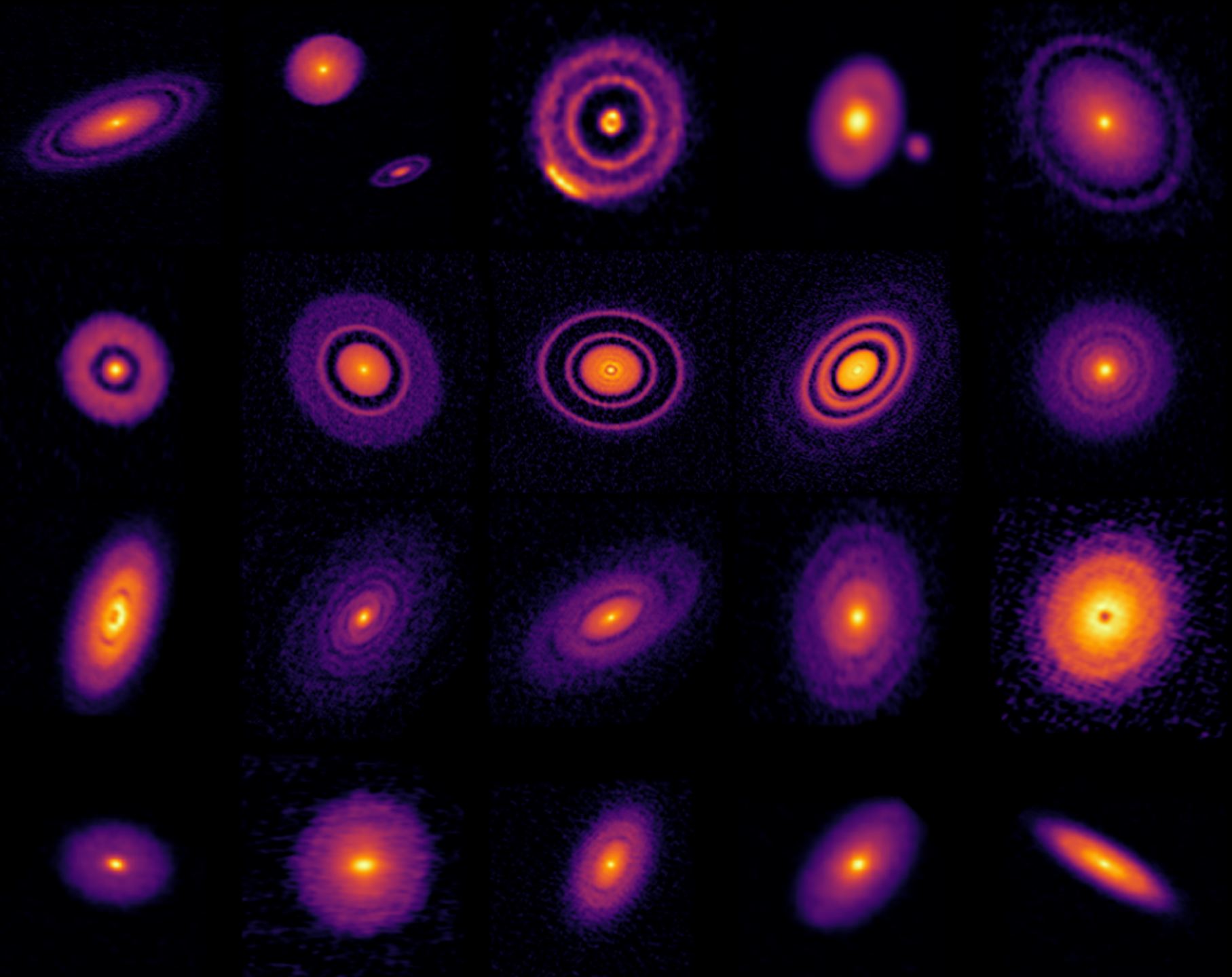


Image credit: ESA



While the star is growing, its disk is evolving.

This is when and where ***planets*** begin to form

Image credit: DSHARP

The gas and dust in the star's disk isn't smooth. Planets grow out of clumps of ***gas, ice, and dust*** in the disk.

The bigger a planet becomes, the more it can grow. Sometimes, planets even leave hints in the disk that they're there.

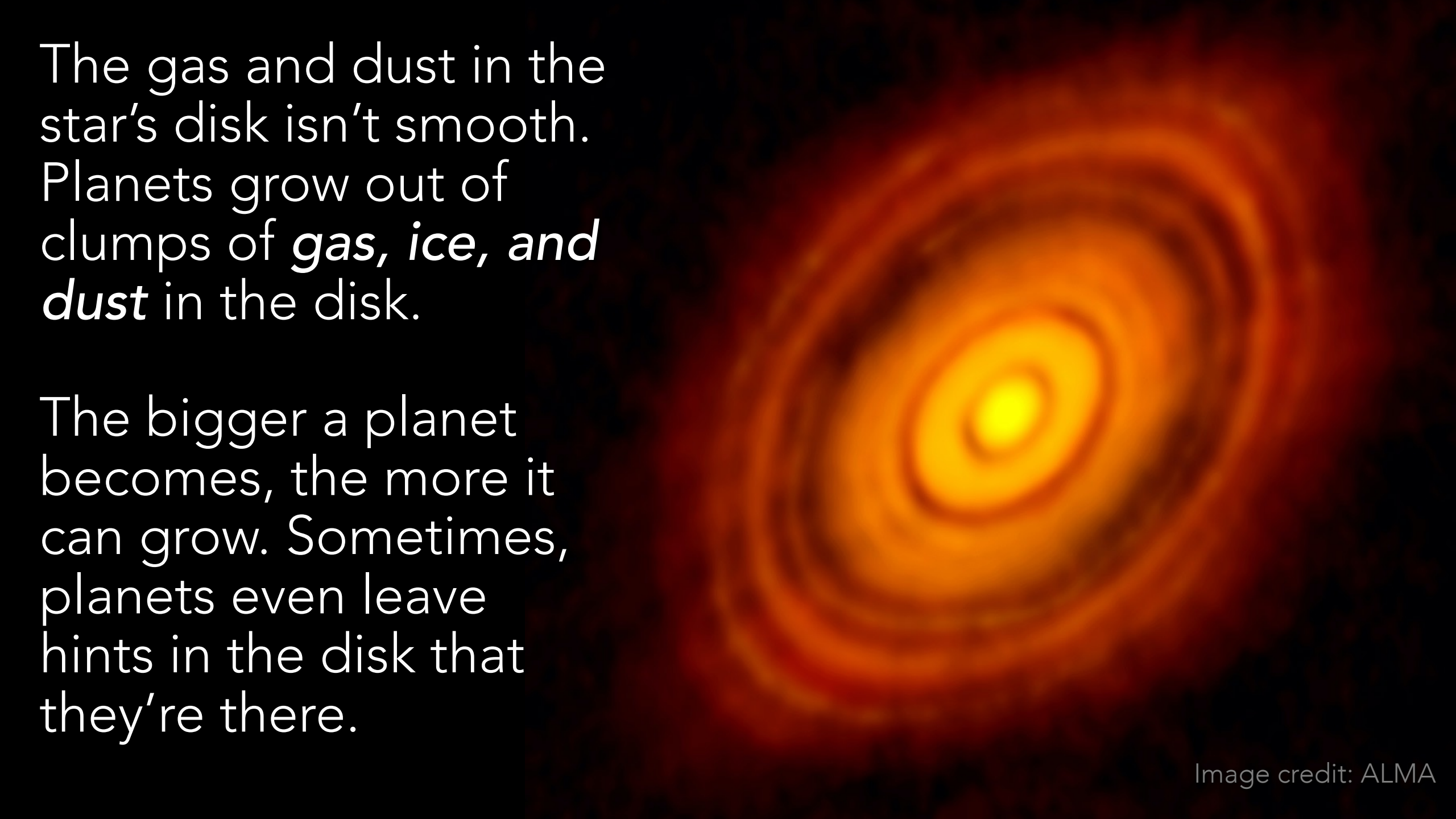
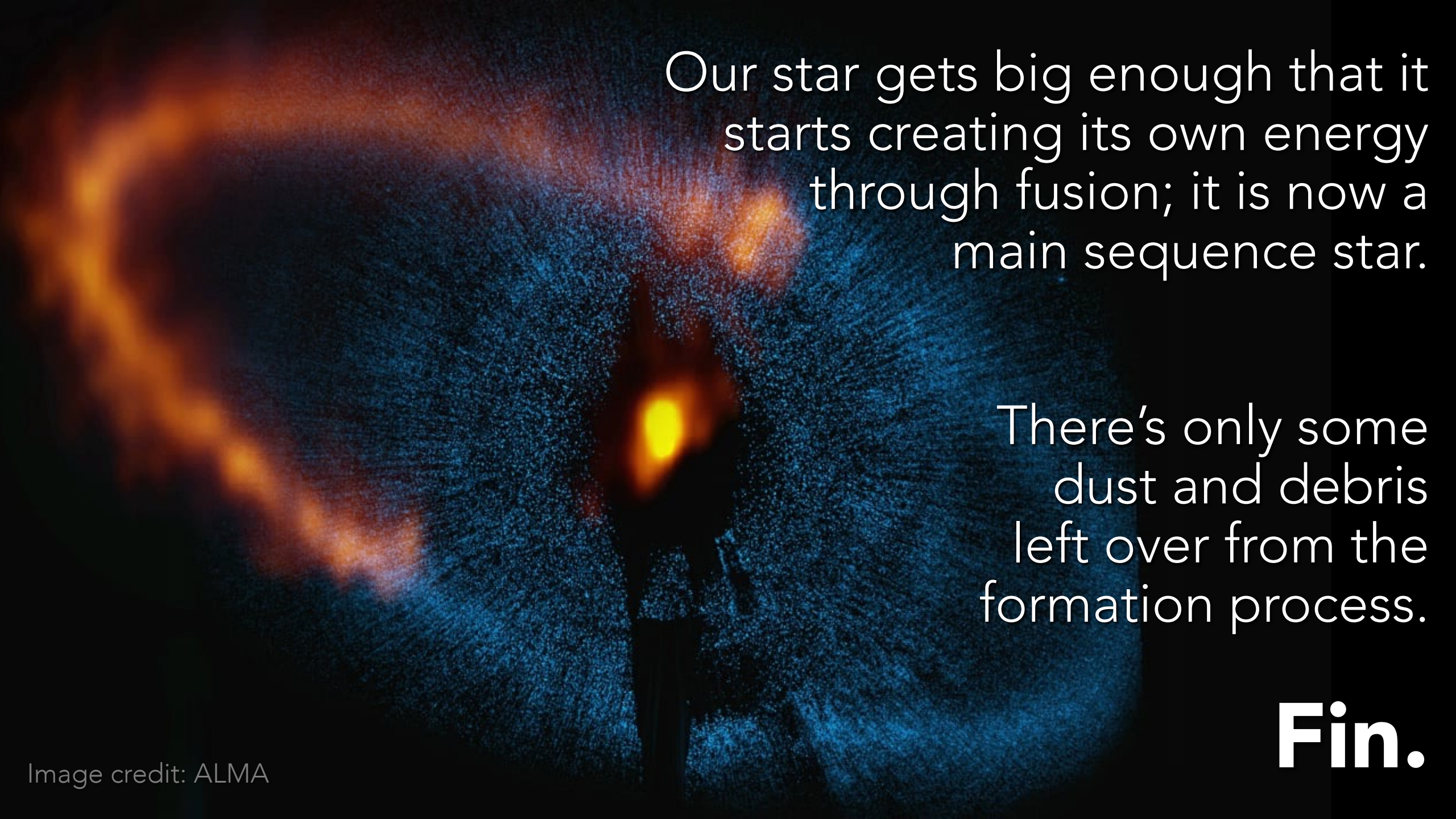


Image credit: ALMA



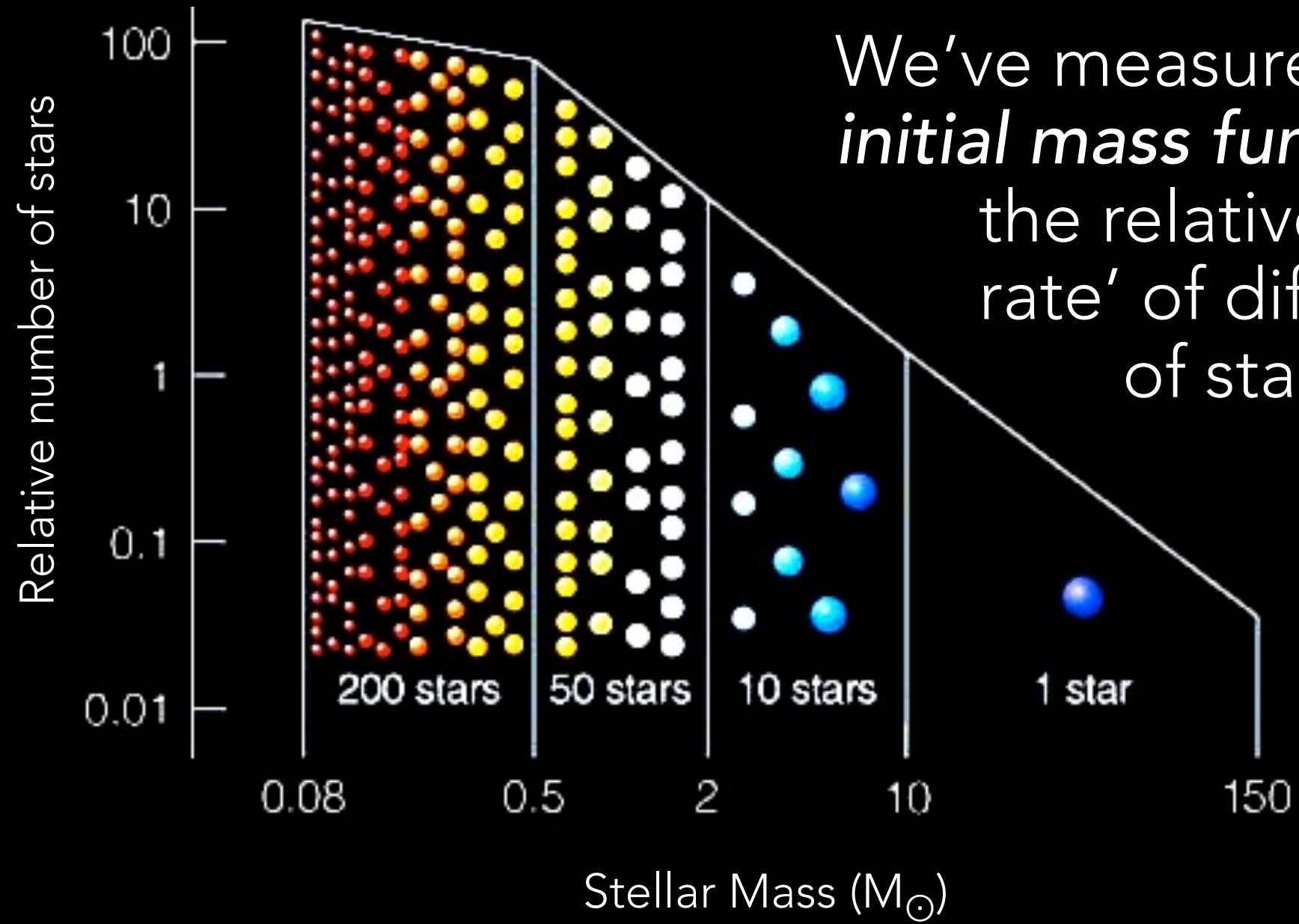
Our star gets big enough that it starts creating its own energy through fusion; it is now a main sequence star.

There's only some dust and debris left over from the formation process.

Fin.

Image credit: ALMA

Now that we know how to make one star, what *kind* of stars does a molecular cloud form?



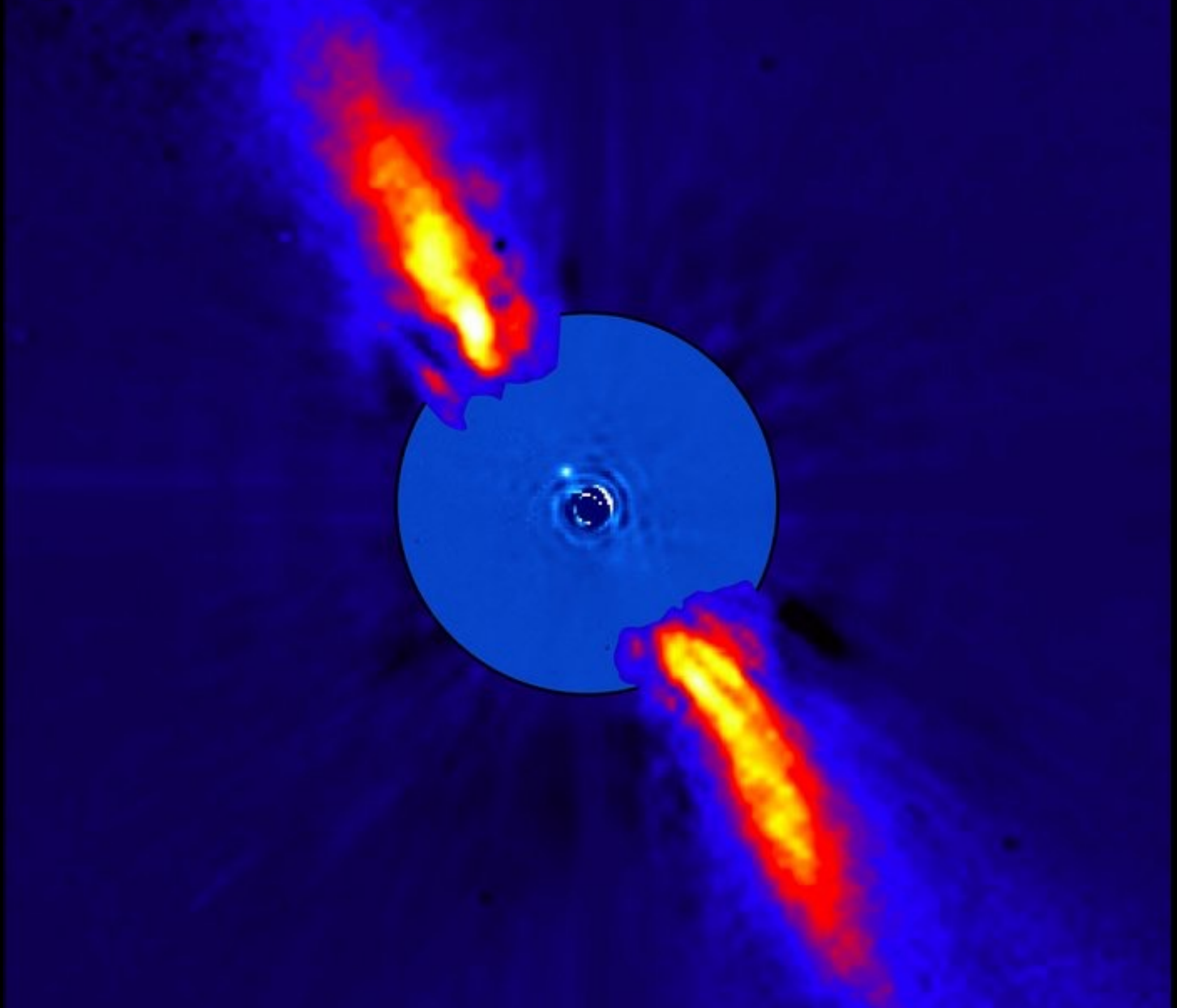
We've measured the ***initial mass function of stars:*** the relative 'production rate' of different types of stars

Image credit: LASP

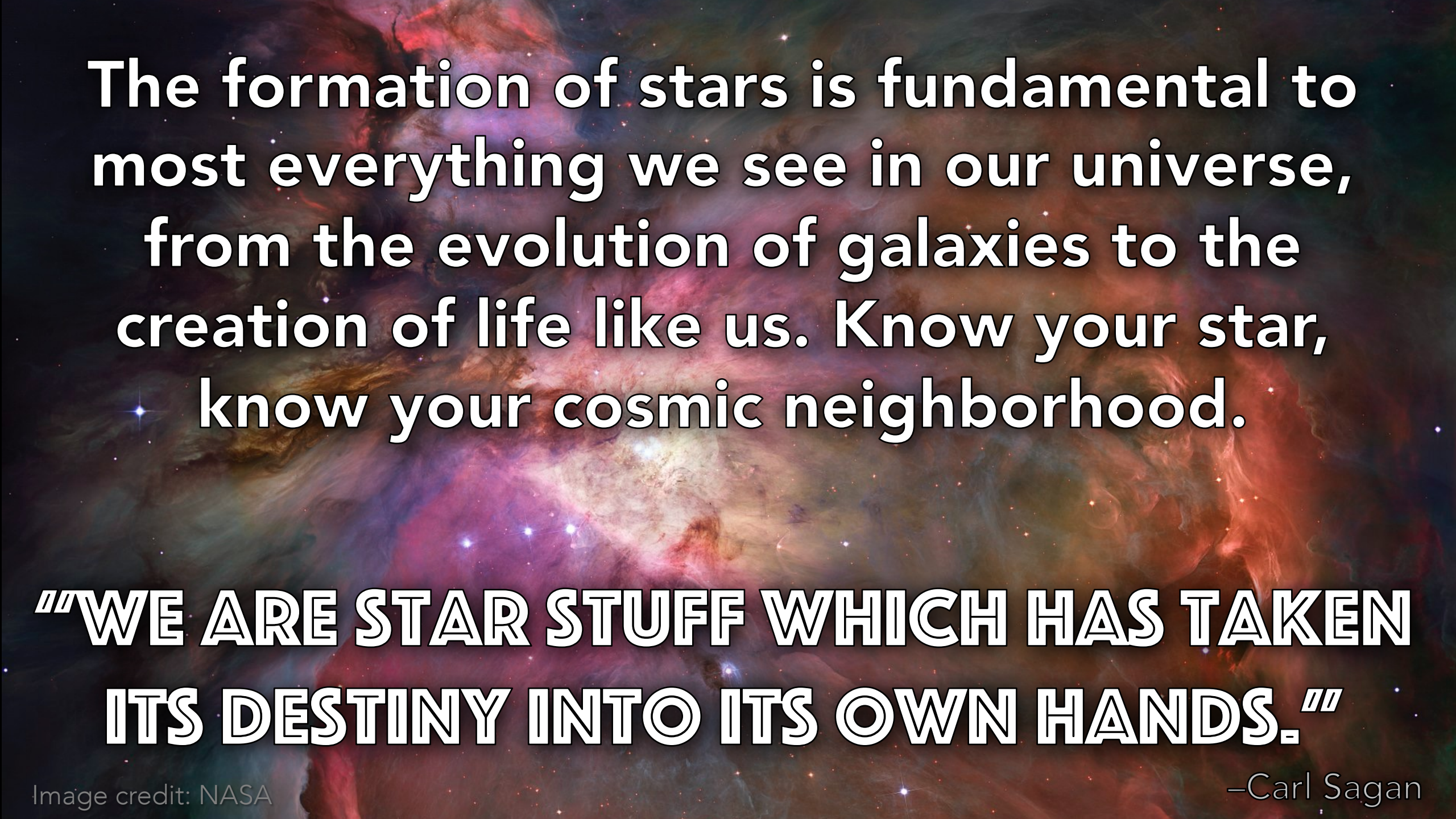
About 50% of all stars orbit another star. These are called ***binary stars***.

Some stars orbit two or more other stars!

ALMA (ESO/NAOJ/NRAO), Alves et al.



Based on data to date, there is an average of ***one planet per star*** in the galaxy


The formation of stars is fundamental to most everything we see in our universe, from the evolution of galaxies to the creation of life like us. Know your star, know your cosmic neighborhood.
"WE ARE STAR STUFF WHICH HAS TAKEN ITS DESTINY INTO ITS OWN HANDS."
–Carl Sagan
Image credit: NASA